UTC-Semi-Annual Progress Report

Tier 1 University Transportation Center on Improving Rail Transportation Infrastructure Sustainability and Durability

University of Nevada Las Vegas
Virginia Polytechnic Institute and State University
University of Delaware

Submitted to

Denise E. Dunn, Grant Manager
University Transportation Centers Program (RDT-30)
Office of the Assistant Secretary for Research and Technology (OST-R)
U.S. Department of Transportation
1200 New Jersey Avenue, SE, Work Station E33-436
Washington, DC 20590-0001
Phone: 202-366-4985
Fax: 202-493-2993
Email: denise.e.dunn@dot.gov

Submitted by

Hualiang (Harry) Teng, Professor

Department of Civil and Environmental Engineering and Construction
University of Nevada, Las Vegas
4505 S. Maryland Parkway, Box 454015
Las Vegas, NV 89154-4015
Phone: 702-895-4940
Fax: 702-895-3936
Email: hualiang.teng@unlv.edu

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UTC Semi-Annual Progress Report

1. ACCOMPLISHMENTS

Major goals and objectives of the program

The goal of this program is to conduct research, promote education, and facilitate technology-transfer activities to improve the sustainability and durability of the railroad infrastructure in the United States. Forecasts call for the U.S. economy to continue to grow, and freight travel to remain steady or increase slightly. Railroads will play a larger role than ever in carrying this demand. Such increased use, in turn, will expedite deterioration of the railroad system. The future need for faster transfer of goods and people will also necessitate high-speed rail transportation, as has occurred in all developed and developing countries around the world. High-speed rail will place far higher demands on maintaining and sustaining rail infrastructure, which can only be accommodated through advanced technologies such as those detailed within the goals and objectives of this DOT-UTC.

The first objective of the program focuses on four areas of research critical to railroad system operations and safety:

- Asset management and performance assessment
- Condition monitoring, remote sensing, and use of GPS
- Application of new materials and technologies
- High-speed rail (HSR) construction methodologies and management

Virginia Polytechnic Institute and State University (Virginia Tech) focuses on condition monitoring, remote sensing, and the use of laser- and GPS-based systems. The University of Delaware focuses on asset management and performance management using big data (data analytics) techniques, and application of new material, analytic models and technologies. The University of Nevada Las Vegas is engaged in technologies and construction methodologies to better enable further development and implementation of HSR in the U.S.

The second objective of the program is to improve workforce development and rail education in the U.S. through: 1) offering undergraduate and graduate courses to engineering students; 2) establishing certificate programs suitable for the new generation of engineering students and young professionals who wish to get engaged in the rail industry; and 3) providing short courses suitable for practicing engineers who wish to further hone their skills. Toward this end, all three partnering universities are engaged in complementary activities ranging from STEM activities to introduction of railroad-specific undergraduate and graduate courses, workshops, and professional development seminars.

The third objective of this program is to develop and conduct professional activities to disseminate results from the research to industry and academia. Examples of these activities are organizing and attending conferences, seminars, and workshops. We will also write and submit articles for journal publication.

Goal accomplishments

Continuing active research projects

Our consortium universities have continued 16 research projects in this reporting period, four (4) at Virginia Tech, five (5) at the University of Delaware, and seven (7) at UNLV. Significant advances were made in each project. The project progress is described below.

VT-1: Methods for Qualitative and Quantitative Measurement of Top of Rail (ToR) Friction Modifiers in Revenue Service. The primary objective of this study is to continue the efforts toward evaluating, designing, and building highly accurate devices for qualitative and quantitative measurement of Top of Rail (ToR) friction modifiers in revenue service. Two new generations of LIDAR-based measurement were designed and undergone extensive evaluation both in the lab and on revenue-service track. Unable to perform any field tests with our project partner Norfolk Southern due to the pandemic, we limited our activities to laboratory tests and analysis of the data that was collected in the past. The laboratory tests of the prototype system were developed at the Railway Technologies Lab at Virginia Tech (RTL), under precisely controlled conditions (for ToR thickness), confirms the earlier findings. These show that the prototype system is able to provide an accurate qualitative assessment of the amount of lubricant on the rail. The analysis of the past field data revealed a number of interesting findings, in terms of how the railcar wheels interact with the friction modifier deposited on top of the rail and spread it along the path. Most notably, the spread of the material is affected by the wheel load and the number of railcars in the train. Trains with more wheels, and a heavier wheel load spread the ToR farther downstream of the applicator, and with more uniformity. For the first time, to the best of our knowledge, this research shows that the type of trains that operate on a track must be taken into account in managing ToR application, beyond the train traffic that has always been considered by the railroads. One paper was submitted and published in the proceedings of the 2020 ASME Joint Rail Conference (JRC). Another paper that includes our most recent findings is under preparation for publication and presentation at the 2021 JRC, scheduled to be held virtually in April 2020.

VT-2: Monitoring and Detecting Fouled Ballast using Forward Looking Infrared Radiometer (FLIR) Aerial Technology. Ballast fouling costs the railroads hundreds of millions of dollars per year in maintenance of the way costs, service interruption, and other ancillary expenses. The primary objective of this research is to explore application of FLIR for assessing fouled ballast on tracks in its early stages, before it develops into a major maintenance project. Using off-the-shelf FLIR technology, the proposed method takes advantage of temperature differences measured by the FLIR camera between the top surface of clean and partially fouled ballast samples as an indicator of fouling. The majority of our efforts during this reporting period concentrated on documenting and further analyzing the tests that had been carried out earlier under tightly controlled conditions. The test conditions included various stages (amounts) of fouling, different depth of fouling (surface, sub-surface, deep), within various temperature ranges. Laboratory tests used FLIR cameras to measure the thermal behavior and characteristics of ballast in different conditions, namely clean, partially-fouled, and fully-fouled. Results indicate that the cooling and heating rate at the top surface for clean, partially fouled, and fouled ballast are different during the daily heat-up and cool-down cycles. It was determined that although the FLIR camera can measure some changes in the ballast temperature, the differences may be within the range of variations that could occur for field conditions. The results of the study further highlight the pros and cons of using FLIR cameras for rail applications. The results of the study have been documented in a comprehensive DOT-UTC report, and in two papers that were published in the proceedings of the 2020 ASME Joint Rail Conference (JRC). The presentations associated with the two published papers will be made in April 2021, since the 2020 conference was cancelled due to the pandemic. No additional testing of this technology is planned during 2021 due to the difficulties associated with COVID-19. We plan on evaluating all available options at the end of 2021 and proceed with the best feasible approach.

VT-3: Application of Doppler LIDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. Gage widening due to track foundation softness or misalignment in curves can cause gage-widening derailment. The primary objective of this study is to evaluate the application of Doppler LIDAR sensors for in situ assessment of track gage widening in curves and locations with high-lateral forces. The proposed method uses track measurements by two low-elevation, slightly tilted LIDAR sensors nominally pointed at the rail gage face on each track. The LIDAR lenses are installed on board a Hyrail truck with a slightly forward angle to measure track speed in both longitudinal and lateral directions. During this reporting period, we made excellent progress with upgrading two LIDAR measurement systems that had been used in the past for track gage and speed measurements. Both the system hardware and software have undergone major changes to what we had used in the past. The systems are currently undergoing bench-top system integration testing, before they are deployed to the field for testing. Currently, no field testing is planned until mid-2021 due to COVID-19. We will re-assess the best method of testing once the current national restrictions are lifted.

VT-4: Application of Machine Learning Techniques Toward Time-based Changes in Track Condition using Onboard Sensors in Revenue-Service Rolling Stock. The primary objective of this study is to evaluate the application of machine learning techniques toward time-based changes in track condition using an onboard sensor in revenue-service rolling stock. Within a framework, an automated process is envisioned for processing field data that is collected, repeatedly on a segment of revenue service track. To account for the stochastic nature of collected data, associated with the temporal mismatch between shifted time-series across different runs, we adopted the Matrix Profile concept, without relying on time series synchronization. The preliminary findings of the study thus far indicate, among a total of 84 identified defects, 67 of them were successfully detected by the method, corresponding to a rate of 80%. Although this is an excellent rate of defect detection, far more field data is needed to further validate the early findings. Due to the significant downturn in passenger traffic on Amtrak, and the ensuing workforce reduction from the pandemic, the original plans we had for testing the method in the Eastern Corridor are currently on hold. We intend to shelf this project in 2021, hoping we will regain the opportunity to test with Amtrak, or another Class I railroad in 2022.

UD-1: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. Phase I of the model is complete and Phase II began in 2019. Work continued on Phase II of the rail wear model. With additional rail profile data collected very frequently, algorithms for projecting the cross-sectional shape of the rail are being developed, utilizing methodologies previously developed on the single dimension case. A two-dimensional Auto Regressive Integrated Moving Average (ARIMA) methodology is currently being developed that will allow for a data driven constrained growth model of the rail's surface due to wear. UD is working with Amtrak to develop, and implement this new model, using rail wear data from Amtrak's high-speed Northeast Corridor. The objective is to introduce this new rail wear forecasting model into Amtrak's rail maintenance planning and budgeting activity. This activity has been delayed due to coronavirus.

UD-2: <u>Rail Fatigue Life Forecasting Using Big Data Analysis Techniques</u>. This activity has concluded. The result was a new method of performing Weibull analysis of rail defect data, using Parametric Bootstrapping for the Weibull analyses for the prediction of rail defect development. This new approach results in an ability to forecast the probability of rail defect occurrence as a function of cumulative tonnage experienced by the rail, and other key track and traffic parameters that affect development of fatigue defects. A UTC report on this work was submitted in September 2020. A journal papers was also submitted in September 2020.

UD-3. <u>Principal Components and Development of a Combined Track Quality Index (TQI)</u>. This activity is completed. This study employed a linear and nonlinear dimension reduction technique that expressed the probability distribution of observations based on the similarity or dissimilarity in their embedded space, whilst also maximizing the variance in data. This study found an application in principal component analysis (PCA) and T-Stochastic neighbor embedding (TSNE) for separating geometry defects from higher dimensional space to lower dimensions. Results showed that while both techniques effectively reduce track geometry data, PCA yields a potential defect probability threshold, despite that TSNE is a better geometry defect predictor. A UTC Report was submitted in October 2019.

UD-4: <u>Load Transfer from Track to Bridge Structure on Curves</u>. This project began in September 2019, and addresses the issue of transfer of thermal longitudinal rail forces from track to bridge structure on curved track. The design of a railway bridge is significantly different from that of a conventional highway bridge because of the additional loading imposed onto the bridge due to the track structure behavior under vehicle and thermal loading. This difference is further enhanced on curves, where the bridge is supporting a track with curvature. The focus of this research is on the effect of thermal forces on welded rail in bridge structure curves. The presence of a curve results in this force having a lateral as well as a longitudinal component. To date both theoretical models based on fundamental research by Timoshenko and also by A. D. Kerr have developed as well as a finite element model and the results have been compared with excellent agreement. A UTC report and a journal paper are currently in preparation. Note that SEPTA is partnering with the University of Delaware and will provide engineering and technical support.

UD-5: <u>Track Geometry Models using "Small Data" Algorithm</u>. This project is ongoing and addresses the use of "small data" algorithms for track geometry modeling. Track geometry quality is directly linked to vehicle safety, reliability and ride quality. Track performance is therefore considerably affected when track geometry deviates from the specified limits due to load weight and continuous usage. Analysis of track geometry data can allow for the prompt application of preventive and corrective maintenance measures, like tamping, to increase track lifespan and provide higher train speeds, thus optimizing track performance. The first section of this research focused on the implementation of Approximate Bayesian Computation (ABC), also known as the likelihood-free method, in estimating parameters of track degradation models for track maintenance. The second part of this research compares ABC models to a Bayesian nonparametric models (Gaussian Processes) to select the best track degradation model. A UTC Report was submitted in February 2020. A paper, "Approximate Bayesian Computation for Railway Track Geometry Parameter Estimation," has been accepted by the Journal of Rail and Rapid Transit for publication.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairmen. In this reporting time period, the shielding gas arc welding technique was used to repair a worn rail; and the repaired rail is under lab test. The submerge arc welding technique is being prepared to repair a worn rail by a trained professional. The welding will be conducted in the next half year. At the same time, a twin-disc rolling contact fatigue tester was designed. It will be built in the next half year, after reviews by identified experts. Two journal papers have been written based on prior research work and are under review.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. In the last half year, the research has focused on the determination of the annual access charges that XpressWest (XW) should pay the California High Speed Rail System (CHSR), for sharing the use of the Palmdale - Los Angeles segment of the CHSR network. The access charges would be based on train-hours of operations with the following costs: track infrastructure maintenance costs, system operation costs, capital recovery costs (initial investment and replacement of track system components over the design life of the system, and incident impact costs). To achieve this research objective, literature on access charges for European HSR systems was reviewed. Data was obtained from the International Union of Railways (UIC) and other sources on maintenance and operating costs of high speed rail systems. Mathematical models for the calculation of access charges on different high-speed railway systems in Europe were searched and reviewed. The CHSR Business Plan was reviewed, which contains estimated system costs including: capital costs of the track systems, maintenance, and operation costs. Incidents rates on HSR Systems were searched and reviewed in order to determine the impact of potential XW incidents on CHSR operations. This is a two-step process that involves: (1) using the Vissim simulation to estimate the impact on CHSR trains per XW train incident in delays per train; and (2) estimation of the number of such incidents per year based on incident rates data from other HSR systems.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The team implemented a new solution with a field programmable gate arrays/system-on-a-chip (FPGA/SoC) system, after identifying an incompatibility issue with the original acoustic sensor system. Laboratory tests with this FPGA/SoC system with an added preamplifier were successful, but the team encountered other problems (i.e., high temperature, data glitch and loss) during testing in the field. Despite various attempts to resolve the persistent issues, such as data loss and the high temperatures over 70 degrees on the surface of the chips were found. For improved data collection, the team-initiated Plan D with a new data acquisition module (DAQ) from National Instrument (NI) to convert the analog signal to digital data. The team is in the process of configuring the software and hardware with this NI DAQ system to prepare for on-field data collection. Further, the team performed a set of tests to check signal attenuation while signals propagate through multiple surfaces contact interfaces. The test comparisons indicate a similar range of acoustic signal values and similar energy loss, which do not significantly affect the capability of defect detection.

UNLV-4: Development of a Platform to Enable Real Time, Non-disruptive Testing and Early Fault Detection of Critical High Voltage Transformers and Switchgears in High-Speed Rail. The team has mostly completed part of the high frequency data collection, using field-programmable-gate-array (FPGA) with 50MHz ~1GHz oscillator frequency (i.e. ~2 Gigabyte per second). Since most data saving approaches need to work with the operating systems (which is quite challenging for signals in the range of GHz for regular embedded systems), the team is working on various data recording or transmission approaches, such as Peripheral Component Interconnect Express (PCIe) or (Universal Serial Bus) USB 3+, etc. to properly record a large amount of data thus generated. Due to COVID-19, the team is working from home to advance the project.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. In this reporting period, a literature review was conducted. Sample preparation is in progress. Due to COVID-19, with the closure of the laboratory, we expect to get behind for completion of the project by roughly 9-12 months. One journal paper was submitted for publication and is under review; two technical papers are being prepared for submission to journals for publications.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. Due to the low point cloud density using Velodyne 16-beam LiDAR, the team is exploring other commercially available LiDARs, including: Livox-Horizon, Ouster OS1-128, Intel Realsense L515, to see which works for this target application. These LiDARs have their own software visualization tool to display 3D point clouds in their respective visual interface, yet do not allow users to operate on the raw point cloud data directly in each frame, and such data is critical for analysis and processing, pertaining to this application. The team is developing new software tools to extract 3D point cloud data at the frame level for each LiDAR. Meanwhile, the team is transplanting data acquisition programs onto Raspberry Pi (RPi), which is mounted on UAV to help gather data in the field. Once all the raw 3D cloud point data is collected and accessed through RPi, the team will mount it onto the UAV for field test, and send this data to train the machine learning networks targeting object segmentation and recognition, and thus to measure the geometry for each object of interest.

UNLV-7: Transit Degradation Monitoring and Failure Prediction of Carbon Strip in Pantograph. The weakest link in powering high-speed rail locomotives is the carbon strip of a pantograph collector which makes physical contact between the overhead power line and the electrical supply wires of the locomotive. This project aims to determine the degradation effects of the carbon strip by monitoring the current in the locomotive's input power line. During this reporting period, we developed and perfected the electromagnetic dot based on stripline/microstrip configurations. These dots were manufactured by third party printed circuit board (PCB) vendors, for quality assurance and are currently assembled at UNLV. Similar to the coaxial based EM dots, the microstrip based dots are calibrated over the frequency range of 100 KHz to 1 GHz and 1 GHz to 5 GHz. Calibration over the frequency range (between 1 GHz and 5GHz) was performed in an electromagnetic anechoic chamber at UNLV. Under the same conditions, EM dot sensors based on coaxial cable technology, and those based on stripline/microstrip technology yield about the same absolute measurement of the discharge current passing through the carbon strip. The acquired commercialized carbon strip from Schunk Carbon Technology, LLC was accentuated with a number of normal and abnormal wear and tear patterns. These patterns are on the scale size of the high power line diameter. The resistance of the carbon strip over these patterns was characterized with the high voltage line making contact with the carbon strip, and the metal frame that houses the carbon strip. As indicated in other sources in literature, typical forces between 20 and 40 lbs. are appropriately applied when performing resistor measurements at various locations along the strip. The recommended pound force is 30 lbs. Laboratory data is currently being collected and evaluated over the carbon strip anomalies. All experiments are performed in a static state. Our final objective, based on this data, is to predict when the carbon strip must be replaced.

Initiating new research programs

In this reporting period, UD initiated a new research project: UD-6. Effect of Adjacent Poor Ties on Wood Crosstie Life. This research activity studies the effect of adjacent tie conditions on the life of a railroad cross-tie. Using automated crosstie inspection taken from the same track in multiple years, the goal is to develop improved tie life models, taking into account local conditions. Using these different tie conditions, and the corresponding different periods in the lifespan of a tie, the project will look to determine the average tie life, by mathematical modeling techniques such as piecewise reconstruction. The aim of this activity is to provide a method to predict and model tie life, based on support conditions as defined by the condition of adjacent cross-ties. The analysis approach will use Dijkstra's algorithm, together with tie condition data from two different inspections performed within a span of 3 years.

Upgraded education opportunities

Virginia Tech plans to offer a distance learning graduate course on "Rail System Dynamics." This course could potentially be broadcast to the University of Delaware and UNLV. Additionally, VT plans to offer a one-day professional development seminar on Fundamentals of Rail System Dynamics on May 18, 2020. in 2021 at a suitable date. The exact plans are currently on hold due to the challenges created by the pandemic.

At the University of Delaware, a new professional development course "Rail Grinding and Rail Maintenance" was scheduled for delivery to Amtrak in March 2020 but has been delayed due to the coronavirus. UNLV offered a "Railroad Engineering" course in the Spring semester of 2020 and a "High Speed Rail" course in the Fall semester of 2020, which is a way to prepare the workforce for the high speed rail project planned to connect Las Vegas of Nevada, and Los Angeles in California.

Opportunities for training and professional development

Virginia Tech made final plans to offer a professional development seminar on May 18, 2020 in Roanoke, Virginia, in conjunction with the second RailTEAM Symposium on Track Maintenance Diagnostics and Prognostics until forced cancelation. The symposium was intended to provide ample training and professional development for rail engineers, researchers, and scientists in the area of improving track maintenance practices. The event was cancelled due to the shutdown created by the COVID-19 emergencies. The tentative plans for offering the seminar and symposium in 2021 are currently on hold until 1Q'21, with hope that there will be more certainty with the pandemic.

The University of Delaware's Professional Engineering Outreach provides professional courses for practicing railroad and transit professionals. These professional development courses include Application of Emerging Data Science Techniques for Railway Maintenance Planning, given in December 2019 as well as Rail Grinding and Rail Maintenance scheduled in March 2020; and Rail Industry Growth for Increased Long-Term Profitability scheduled for October 2020.

The Big Data in Railroad Maintenance Conference is held annually at the University of Delaware and co-sponsored by the RailTEAM UTC in December each year. This conference addresses the growing use of data analytics in railroad maintenance planning and management and draws over 200 attendees from railroads, transit systems, railway suppliers, data analytic companies and academia. The upcoming 2020 conference is scheduled for December 16, 2020, and will be in a virtual format. The program has been set up and registration has already started.

UNLV plans to host a webinar on high speed rail design and construction, and to present the design and construction standards in constructing high speed rail in the U.S.

Results disseminated

The current pandemic has created significant challenges with disseminating our results. The plans for attending conferences and meeting with industrial partners were canceled due to the pandemic shut down. As mentioned earlier, the coronavirus has also affected our initiative to organize a symposium and workshop in May 2020. We are currently evaluating the best path forward for 2021. We have plans to present the results of our projects at next year's ASME Joint Rail Conference in April 2021.

The University of Delaware conducted two major activities to disseminate results to industry and academia. The annual "Big Data" in Railroad Maintenance Planning was held on December 11-12, 2019 and was once again a resounding success, with more than 200 professionals from a spectrum of companies, universities, and government agencies attending the one and one-half day event. RailTEAM project results were presented by speakers from both the University of Delaware and Virginia Tech. The next conference is scheduled for December 16, 2020 in virtual format. During the 2019 conference, presentations by Joe Palese of the University of Delaware and Mehdi Ahmadian and Milan Afzalan of Virginia Tech dealt directly with UTC projects in addition to presentations by Nii-Attoh-Okine and Allan Zarembski of the University of Delaware. The 2020 conference again features UTC related presentations by Mehdi Ahmadian of Virginia Tech and Nii-Attoh-Okine and Allan Zarembski of the University of Delaware.

Likewise, the University of Delaware maintains contact with industry partners and its own railway advisory board to present UTC project results. In particular, the recently completed fatigue analysis project as well as the ongoing rail wear project was presented to UD Railway Advisory Board in June 2020, as well as a presentation of results to the American Railway Engineering and Maintenance of way association (AREMA) in September 2020.

Plan for the next reporting period

Two of the research projects that we currently have (VT-2 and VT-4) will be on hold at the end of 2020 until further assurances are given for the pandemic. The other two projects (VT-1 and VT-3) will continue in 2021. We will also initiate two more projects in 2021, one related to wayside energy harvesting for applications, such as extending the flight range of drones; and another one related to the frictional effect of third-body layers at the wheel-rail interface.

At the University of Delaware, we plan to continue research activities with our graduate students and research scientists. We estimate publishing two to three journal papers and making two to four presentations. UNLV will continue with seven research projects, some of which will be completed in the next reporting period. At least four research papers are under review or in preparation and may be published in the next reporting period. A webinar will be hosted on the high speed rail.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Virginia Tech maintains some level of collaboration with Norfolk Southern (NS) and Amtrak, although both have been affected by the pandemic. During this reporting period, we have forged a new relationship with the Transportation Technology Center, Inc. (TTCI), the R&D arm of the Association of American Railroads (AAR) that consist of Class I railroads. This relationship is expected to bring both in-kind and cash matching funds to our DOT-UTC efforts.

At the University of Delaware, Phase II of the rail wear project will have data and technical support from Amtrak's Engineering Department (Philadelphia, PA) as well as ongoing support and data from CSX Transportation in Jacksonville, FL. CSX is also providing rail data for the rail fatigue project. In addition, the track-bridge interaction project is getting technical support from SEPTA (Southeastern Pennsylvania Transportation Authority) with headquarters in Philadelphia PA. In-kind support with SEPTA engineering personnel will provide technical information, support and guidance, including engineering details on track and bridge interaction design on SEPTA's elevated structures.

Nevada Southern Railroad Inc. (NSRI) has provided equipment, spaces, and staff for conducting research supported by the UTC program. For the project developing acoustic sensor detecting rail internal defects, the NSRI allocated a segment of rail track that was renovated with rails of certain defects. They also dedicated a rail vehicle which the developed sensor can be installed on. Their staff assisted in renovating the track: cutting the rail and reinstalling the track. They also trained our student to operate the rail vehicle. NSRI provided space for storing rails for the research projects. Their staff assisted our students with getting rail samples for our 3D printing project. They allowed our students to fly a drone over their tracks, testing our system to measure the track irregularities.

Other collaborators or contacts involved

None to report during this period.

3. OUTPUTS

Output performance measures

In this reporting period, our center has published nine papers on conferences or technical journals which far exceeds our target: six to eight papers in a year. We do not have any invention disclosures and provisional or utility patent application filed, which is still within the range of our targets (0.5 each half year, respectively). It is perceived that these two performance measures would increase with more projects completed, that have been delayed due to the pandemic.

Publications, conference papers, and presentations

The presentations and publications developed by our UTC team in this reporting period are listed below.

Publications

1. Mast, T., Neighborgall, C., Peterson, A., Holton, C., and Ahmadian, M., Sensor Selection Consideration for Top-of-Rail (TOR) Lubrication Detection, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
2. Radmehr, A., Ahangarnejad, A.H., Tajaddini, A., and Ahmadian, M., Surface Profile and Third-body Layer Accumulation Measurement Using a 3D Laser profiler, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
3. Afzalan, M., Jazizadeh, F.K., and Ahmadian, M., Towards Railway Automated Defect Detection from Onboard Data using Deep Learning, Proceedings of the 2020 Joint Rail Conference, St. Louis, Mo, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
4. Radmehr, A., Ahangarnejad, A.H., Tajaddini, A., and Ahmadian, M., Influence of Angle of Attack on Wheel-rail Interface (WRI) Dynamics Under Various Friction Conditions,

Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)

5. Tan, Y., Hosseini, S-M, Chen, Y., and Ahmadian, M., Simulation Evaluation of Fouled Ballast Thermal Characteristics, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
6. Dama, N. and Ahmadian, M., Discrete Element Modeling of Railway Ballast for Studying Railroad Tamping Operation, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
7. Hosseini, S-M, Tan, Y., and Ahmadian, M., Forward-Looking Infrared Radiometry (FLIR) Application for Detecting Ballast Fouling, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
8. Radmehr, A., Ahangarnejad, A.H., Pan, Y., Tajaddini, A., and Ahmadian, M., Wheel-Rail Contact Patch Geometry Measurement and Shape Analysis Under Various Loading Conditions, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. UTC support acknowledged. (Virginia Tech)
9. Alsahli, A, Zarembski, A.M., and Attoh-Okine, N., Predicting Track Geometry Defect Probability Based on Tie Conditions Using Pattern Recognition Techniques, Proceedings of the ASME International Mechanical Engineering Congress and Exposition (IMECE2020), Portland, OR, November 2020. UTC support acknowledged. (University of Delaware)
10. Cronin, J.J., Zarembski A.M., and Palese J.W., Prediction of Rail Defect Development Using Parametric Bootstrapping Modified Weibull Equations, submitted to The Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, September 2020. UTC support acknowledged. (University of Delaware)
11. Ashley, G., and Attoh-Okine, N., Approximate Bayesian Computation for Railway Track Geometry Parameter Estimation", accepted by The Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, September 2020. UTC support acknowledged. (University of Delaware)
12. Hasnat, A., and Ghafoori, N., Freeze-Thaw Resistance of Non-Proprietary Ultra High Performance Concrete, submitted to the ASCE Journal of Cold Regions Engineering, June 2020. UTC support acknowledged. (UNLV)
13. Mortazavian, E., Wang, Z. and Teng, H., Finite Element Analysis of Thermal Kinetic-Mechanical Evolutions during Laser Metal 3D Printing Process as a Potential Technique for Rail Repair, submitted to the Journal of Manufacturing Science and Engineering, April 2020. UTC support acknowledged. (UNLV)
14. Mortazavian, E., Wang, Z. and Teng, H., A Finite Element Investigation on the Effect of Preheating and Deposition Material Type on the Residual Stress in a Rail Repaired via Laser Metal 3D Printing, submitted to the Journal of Additive Manufacturing, September 2020. UTC support acknowledged. (UNLV)

Presentations

1. Zarembski, A.M., Effect of Tie Condition Distribution on Life Expectancy of Wood Crosstie, American Railway Engineering Association Annual Conference, virtual conference, September 2020.

Policy Papers

None to report

Website

Virginia Tech has developed a new and improved website for publicizing its domain. Many of the DOT-UTC initiatives have been included at the Center for Vehicle Systems and Safety's new web site (http://www.cvess.me.vt.edu), as well as RailTEAM's webpage (https://www.unlv.edu/railteam). The University of Delaware has continued to highlight the railway research and educational activities in their Railroad Engineering and Safety Program website (railroadengineering.engr.udel.edu/). UNLV routinely updates the RailTEAM website with information from partnering universities.

Technologies or techniques

The body of knowledge related to application of FLIR technology for railroad/transportation applications (VT-2) has increased through our efforts at Virginia Tech. Our study has scientifically highlighted capabilities and limitations of the FLIR technology for early assessment of ballast fouling, beyond its conventional use for military and limited number of civilian applications. Additionally, the use of LIDAR systems in VT-1 and VT-3 for track applications has significantly improved the knowledge base on how optics sensors can be used for high-fidelity and precise measurements in railroad environment.

The University of Delaware developed noteworthy maintenance models. One is the method/model for predicting wear life of railway rails that was presented at Big Data in Railway Maintenance 2019 conference, December 2019. The other model is new track quality index for maintenance planning, included in a paper presented at the IEEE Big Data 2019 Conference, Los Angeles, CA.

UNLV is the first institution to find that Vissim is a simulation software that can be used to simulate train movement over a high-speed rail network. The high-speed rail simulation model developed at UNLV provides an alternative to existing simulation models in railroad industry that are either too expensive to use or over-simplify railroad operations.

Inventions, patent applications, and/or licenses:

None to report.

4. OUTCOMES

Passage of new policies, regulation, rulemaking, or legislation

The University of Delaware has delivered wear degradation and vehicle performance results to NYCT to help them modify and upgrade maintenance standards and policies. The University of Delaware is working with Amtrak to develop new tools for improved rail maintenance management.

Increases in the body of knowledge

The body of knowledge related to the application of FLIR technology for railroad/transportation applications (VT-2) has increased through our efforts at Virginia Tech. Our study has scientifically highlighted the capabilities and limitations of FLIR technology for early assessment of ballast fouling, beyond its conventional use for military and limited number of civilian applications. Additionally, the use of LIDAR systems in VT-1 and VT-3 for track applications has significantly improved the knowledge base on how optics sensors can be used for high-fidelity and precise measurements in railroad environment.

The research at the University of Delaware deals with new generation data analytic tools to increase the amount of railroad inspection and operations data and development of new relationships between performance, component degradation, and safety. Current research activities already address this in the following areas: wear of railway wheels, wear of railway rails, railway rail fatigue, track geometry degradation, and derailment forecasting.

Improved processes, technologies, techniques and skills in addressing transportation issues

Early results from the VT-1 project indicates strong potential to improve track lubrication processes in terms of the amount ToR friction modifiers are applied to the rail. Better understanding of how far ToR migrates on the track from its application location will also assist with better placement of applicators on track relative to curves, etc.

Research by the University of Delaware provides new analytical tools to address key rail transportation issues. These include degradation/failure mechanisms for both track and vehicle components, specifically wheels, rails, track geometry, and CWR on bridges, which represent critical cost, maintenance and safety areas.

Enlargement of the pool of trained transportation professionals

Close collaboration between Virginia Tech, NS and Amtrak has led to further training for their engineers who are involved with projects in the area of optics sensors and machine learning techniques. The same initiatives are being put in place within the collaboration that has started between Virginia Tech and TTCI/AAR. The Nevada Southern Railroad staff, assisting with the UNLV testing acoustic rail defect sensor, has a better understanding how the rail is inspected manually by using different technologies.

At the University of Delaware, graduate students working on research projects move into the rail and transit industry. One graduate student who worked on the wheel wear project has graduated and taken a position with SEPTA (Southeastern Pennsylvania Transportation Authority). Another PhD student took an extended internship with the US Federal Railroad Administration. Another senior, who works as an undergraduate research assistant, is doing his second summer internship with Amtrak this summer, and expects a job offer from Amtrak which he will accept. We also work with the Washington Area Railway Engineering Society (WARES), which is a Baltimore-Washington DC association of railway engineers that provide an annual award to our graduate students.

The University of Delaware's undergraduate and graduate courses, including its Graduate Certificate in Railroad Engineering trains both undergraduate and graduate students for a railway or transit career. Graduates of the UD program have gone on to work at Amtrak, SEPTA, BNSF, international railways (Brazil, Israel), and several major railway consulting companies (such as WSP, HNTB. Jacobs, AECOM, etc.). The program also trains working professionals who get UD's Graduate Certificate in Railroad Engineering, which includes professionals from Amtrak, SEPTA, US Navy, and numerous consulting groups and international railways.

A senior design team at UNLV worked on a project for designing a railroad vehicle maintenance facility in Victorville, California, which is the end of the high speed rail line connecting Las Vegas, Nevada and Southern California. Some of the students in this team took railroad classes offered at UNLV. In addition, several students have interviewed at XpressWest, the high speed rail company in Las Vegas, Nevada, for job opportunities. A connection with XpressWest has been cultivated for their cooperation with providing seminars, webinars, workshops, and class speech at UNLV in future.

Adoption of new technologies, techniques or practices

University of Delaware's rail wear forecasting methodology is shared with Amtrak who currently work with UD to apply this to their current rail wear analysis and rail replacement planning tools as part of their maintenance planning programs.

University of Delaware's methodology to predict rate of wheel wear as well as identify "bad actor" cars that generate excessive wear (and possibly excessive levels of lateral force) has been shared with New York City Transit (NYCT), the largest transit system in the United States. NYCT is examining how it can be incorporated into their maintenance and safety programs. The work has significant potential for both maintenance and safety since it addresses railway wheels and the point at which they are removed from service for either maintenance or replacement (safety).

Outcome performance measures

In this reporting period, we have 15 citations of our research work, more than the three to five target for a half year. Two pieces of news were covered by both Railway Age and Progressive Railroading in 2020, relating to Big Data in railroad work that were part of our UTC projects with the University of Delaware. They are more than the one to one and a half target/half year we set.

5. IMPACTS

Impact on the effectiveness of the transportation system

In general, much of the research conducted under this UTC activity lends itself to a safer and more reliable railway infrastructure. As accidents in the railway industry draw public attention, improvements in approaches to safety may have a direct impact on society's perception of safety using new and emerging technology. The impact of technologies under development at the RailTEAM UTC are directly related to improving track maintenance practices. U.S. railroads collectively spend billions of dollars in track maintenance. Even small improvements in maintenance of way practices would have a major positive financial impact for the railroads. Technologies that are part of Virginia Tech's studies are those identified by the U.S. railroads as having a significant impact on their revenue service operation. The eventual deployment of both the LIDAR and machine learning technologies are anticipated to have a positive and measurable impact in transportation safety and efficiency. At Virginia Tech, both FLIR and LIDAR technologies, that we currently work on as part of our DOT-UTC efforts, promise significant impacts on the rail industry. These technologies could result in many millions of dollars in annual savings in managing maintenance-of-way for the U.S. railroad industry.

University of Delaware's UTC sponsored research on rail wear is being applied on Amtrak, and specifically Amtrak's Northeast Corridor, in rail replacement planning, a key part of Amtrak's track maintenance program. The University of Delaware is working with Amtrak to collect additional rail profile data for continued efforts on Phase II of the rail wear research project. Amtrak is also providing guidance on practical application of the methodology, as well as data limitations. As this model gets fine-tuned and validated, we expect implementation on many major US rail systems, including freight railways, passenger and commuter railways and rail transit systems.

Also, as reported previously, the University of Delaware extended its developed method to predict the rate of wheel wear. The railways can directly apply models to predict wearing of railway wheels and predict when to either perform maintenance to extend life (e.g., wheel truing) or replace. This information is being examined by NYCT as to how it can be incorporated in their maintenance and safety programs.

A new method of predicting development of rail fatigue defects by the University of Delaware examined use of Parametric Bootstrapping for the Weibull Analyses. This bootstrapped method provides reasonable estimates of defect rates of track segments with no prior defect data, allowing far more data analysis, and accounting for in-maintenance planning efforts, thus increasing rail forecasting effectiveness.

The 3D printing technique applied to repair worn rail would significantly improve railroad productivity, saving on maintenance costs for railroad operation. The UAV technology, being tested at UNLV, would allow more convenient railroad track inspection, saving time in maintaining tracks. In addition, the technology would also allow more tracks to be inspected. The Non-Propriety Ultra-High-Performance Concrete, which is not expensive, was tested in our lab and is exceptionally durable to make railroad ties. This inexpensive concrete can reduce significant construction costs for installing new ties and operation cost in replacing ties.

Impact on the adoption of new practices

Projects at Virginia Tech have not reached a point where the technologies are commercialization ready. The closest is the LIDAR technology being developed in VT-1 and VT-3. This technology could have a significant impact on improving safety and operational efficiency for the rail industry. For instance, the ability to measure the existence or lack of rail lubricant will enable railroad systems to better manage wheel-rail friction at the running surface, hence reduce fuel costs due to rolling resistance at the wheel and also reduce wheel/track wear (and even damage) due to unnecessarily high friction. An additional impact of the technology is in its ability to provide in-situ measurement of track gauge onboard a locomotive or Hy-rail vehicle. Gage widening under high-lateral loads is often the cause of derailment on curves. This technology will enable the railroads to detect and fix “soft” spots on the track, before they become a costly derailment. Again, this will have a significant operational safety and cost impact.

The 3D printing technique applied to repair worn rail and the acoustic rail defect sensor are two products identified by the UNLV commercialization office to have high commercial value. If the 3D printing technique is applied successfully, rail maintenance practice techniques would change significantly. The acoustic sensor can detect internal defects in rail, the biggest threat to railroad safety. Our sensor allows the inspection at speeds up to 220 mph, making track inspection more efficient.

Impact on the body of scientific knowledge

Virginia Tech is developing a LIDAR system that promises significant highway applications for assessing roadway surface conditions, thus, paving the way for a critical technology necessary for semi-autonomous and autonomous vehicles. LIDAR system technology could potentially impact the transportation industry by improving driving safety. For instance, the same technology we use for lubricity detection can potentially assess road surface conditions by detecting black ice and other events not readily visible by drivers. The FLIR cameras being evaluated as part of VT-2 can also detect the presence of trespassers at railroad crossings, beyond what is possible with surveillance cameras installed at some locations. Whereas optical cameras need light to see, FLIR cameras can detect the presence of a warm object, such as a trespasser under all conditions, day or night.

The University of Delaware has developed approaches and methodologies for maintenance of railroad infrastructure that are readily adaptable in the area of highway pavement and airport runway research and analysis.

Impact on the development of transportation workforce development

We are continuing our efforts to educate undergraduate and graduate students for the rail industry, at Virginia Tech. In the past six months, one of our graduate students found employment with a company in the area of data analysis. Two more of our students will be graduating in the next few months, and are considering employment with railroad suppliers upon graduation.

Impacts on the rail industry consist of more informed and educated engineers and scientists who can transmit their knowledge to employers. Another impact is in terms of technology transfer to the industry. Graduates are the conduit for transferring learned technologies, developed in the lab, to their employers in a seamless and organic manner. At the University of Delaware, opportunities for research range from data sciences application to railway degradation analysis and maintenance planning (State of Good Repair). Both undergraduate and graduate students are going into this area under the UTC program. Students are provided with specialized skill sets, such as data analytics as applied to infrastructure conditions.

The UTC program at UNLV continues to provide railroad education by offering courses and holding seminars. The high speed rail project connecting Las Vegas to Los Angeles of California, is planned for construction later 2020. A workforce is highly needed in planning, design and construction of the high speed rail. UNLV continues to provide railroad courses and offering senior design projects on railroad.

Impact performance measures

In this reporting period, one of our stakeholders, AAR/TTCI has requested RailTEAM's expertise in assessing rail stability through the application of LIDAR sensors (Virginia Tech project VT-1). This one case is more than the target (one per year) for the number of stakeholders requesting RailTEAM expertise in the application of research products and/or results. We do not have a single case that involves transferring results to companies, adoption of new practices, or initiation of new startups, which is also within the range of our target, once per year.

6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

COVID-19 has disrupted our research, education and information dissemination activities significantly. The RailTEAM Railroad Infrastructure Symposium originally scheduled for May 19-20, 2020 had to be postponed to 2021 or possibly beyond. Funding from our partnering railroad industry may not be realized. The purchase of some hardware was delayed by several months, which is expected to delay some of the future deliverables for the program. Some lab work cannot be conducted due to the restrictions of the pandemic.

No changes have any significant impact on expenditures. No significant changes in the use or care of human subjects, vertebrate animals, and/or biohazards. No change of primary performance site location from what was originally proposed.

7. SPECIAL REPORTING REQUIREMENTS

Our UTC project complies with the Research Project Requirements and Submission of Final Research Reports.